INFLUENCE OF DIFFERENT TYPES OF OSCILLATIONS ON ION HEATING IN PLASMA-BEAM DISCHARGES

O.F. Kovpik, E.A. Kornilov, S.M. Krivoruchko, S.S. Moiseev, and Ya.B. Fainberg
Physico-technical Institute, Ukrainian Academy of Sciences
Submitted 7 March 1972
ZhETF Pis. Red. 15, No. 9, 501 - 504 (5 May 1972)

It is known that high-frequency and microwave methods of plasma heating are quite promising, especially in large-scale plasma installations (see [1]). Although the question of which wavelengths are better for plasma heating is not so obvious, it seems that from the point of view of plasma confinement it is preferable to use short-wave heating. In fact, the coefficient of diffusion by irregular oscillations is $D \sim \lambda^2$ (λ is a characteristic spatial scale on the order of the wavelength), and therefore, other conditions being equal, large-scale diffusion (and also convection) streams lead to a faster escape of particles and heat from the plasma installation.

The plasma-beam system is convenient for the study of the heating problem, owing to the excitation of a wide class of low-frequency oscillations and to the possibility of controlling their spectrum [2, 3]. It therefore becomes possible to use the same setup to determine the relative roles of different sections of the oscillation spectrum in plasma heating. It follows from the experimental results that low-frequency oscillations, and particularly drift oscillations, develop in a plasma-beam discharge in addition to the high-frequency oscillations, and lead to losses of particles and of heat with a time rate close to the Bohm time (see [3]). This agrees both with the theory of cascaded instability development and with the theory of threshold excitation of low-frequency oscillations by high-frequency ones (see [4 - 6]). It should be noted that the theory of cascade excitation of instabilities is applicable at an arbitrary ratio of the real and imaginary values of the frequency ω.

The growth of the effective collision frequency of the electrons with irregular pulsations $\nu_{e.eff}$ leads to loss of plasma stability [4] and can, for the same reason, also lower the thresholds of parametric excitation of low-frequency instabilities; the order of magnitude of $\nu_{e.eff}$ in an inhomogeneous magnetized plasma reaches large values (thus, upon development of ion-acoustic instability, $\nu_{e.eff} \sim \omega_0(W/P)$, where W is the noise energy and P is the plasma pressure [7]). If the ions are effectively scattered by pulsations of sufficiently high frequency, as for example in the case of excitation of oscillations in the lower hybrid resonance range, then we can apparently expect the appearance of drift modes, since the ion-ion viscosity stabilizes the drift-dissipative instability [8]. We note also that when oscillations develop in the lower hybrid range we can expect also changes of $\nu_{e.eff}$, since, as shown by experiment, the ion-acoustic instability is also suppressed in this case [3].

We present below experimental results that confirm the predominant energy absorption by plasma ions in the region of the lower hybrid resonance $\omega^2 \simeq \omega_i\omega_e/[1 + (\omega_e^2/\omega_0^2)]$ in comparison with heating by oscillations with $\omega \lesssim \omega_i$ (ω_0, ω_e, and ω_i are respectively the electron-plasma, electron-cyclotron, and ion-cyclotron frequencies). A strictly defined oscillation mode was established by the methods given in [3]. The experimental setup is described in [9]. We used a continuous electron beam of 100 mA current and 5 keV energy in a

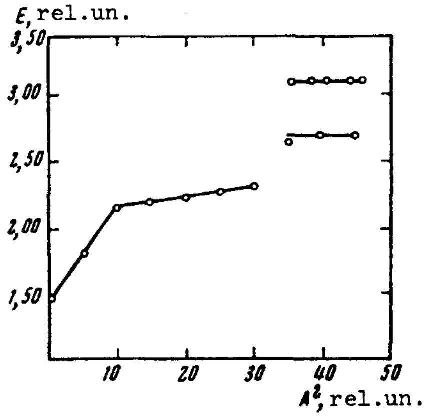

Fig. 1

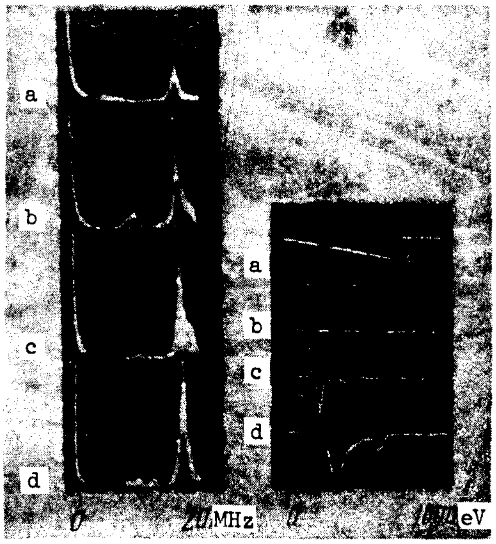

Fig. 2

homogeneous magnetic field of 2 kOe, and the beam produced a plasma of density $(1 - 5) \times 10^{11}\ \mathrm{cm}^{-3}$. The low-frequency oscillations (0.01 - 30 MHz) were excited by low-frequency amplitude modulation of the 3-GHz high-frequency signal used to modulate the electron beam. In addition, the method of modulating with two high-frequency signals [3] was used. The high-frequency and low-frequency oscillations were picked up by probes and analyzed. The energy spectrum of the plasma ions escaping along the electron beam was investigated with an electrostatic analyzer.

The experiment has shown that the maximum contribution to the energy absorption by the ions is made by oscillations near the ion-cyclotron frequency $f \cong 0.072$ MHz and the lower hybrid resonance $f \cong 20$ MHz. Figure 1 shows the dependence of the ion energy on the square of the oscillation amplitude in the region of ω_i, from which it follows that at low amplitudes the ion energy increases linearly, but starting with a certain value A_{cr} the increase slows down. When this "threshold" amplitude is exceeded, drift waves are excited, followed by relaxation oscillations [3]. Figure 2 shows the ion energy spectra (right-hand oscillograms), following excitation at the lower hybrid frequency, as functions of the oscillation amplitudes (left-hand oscillograms). Another characteristic feature is that excitation of oscillations at the lower hybrid frequency and at the same amplitudes as the ion-cyclotron frequency produced no break on the plot of the energy against the square of the amplitude. The width of the energy spectrum turns out to be much larger than in the case of excitation at the ion-cyclotron frequency. Figure 3 shows the experimentally obtained frequency dependence of the phase velocity and confirms that the region $\lesssim 20$MHz corresponds to a fast magnetosonic wave.

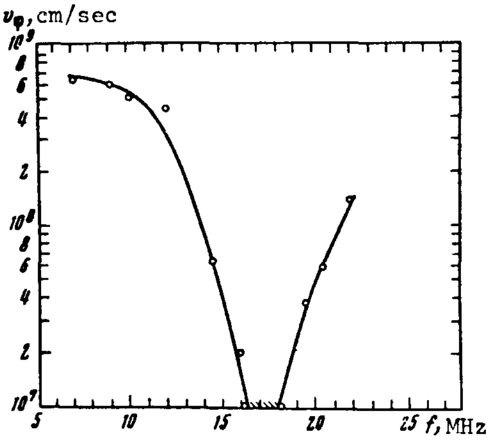

Fig. 3

The results of the experiments agree with the premise that it is most effective to accelerate and heat ions by oscillations that cause little transverse diffusion and thermal conductivity (we see that the ion energy is lower when drift oscillations are excited). It is of interest to carry out similar experiments not only in a plasma-beam discharge. Direct measurement of the effective collision frequencies is also of importance.

The authors are grateful to A.S. Bakai for a discussion of the results and to L.I. Bolotin for interest in the work.

[1] V.E. Golant and A.D. Piliya, Usp. Fiz. Nauk 104, 413 (1971) [Sov. Phys.-Usp. 14, No. 4 (1972)].
[2] Ya. Fainberg, Czech. J. Phys., 18, 652 (1968).
[3] A.S. Bakai et al., Fourth International Conference on Plasma Physics and Controlled Thermonuclear Reactions, Madison, 1971, CN-28/E9.
[4] E.Ya. Kogan, S.S. Moiseev, and V.N. Oraevskii, Prikl. Mat. Teor. Fiz. 6, 41 (1965).
[5] A.B. Mikhailovskii and K. Jungwirth, Zh. Eksp. Teor. Fiz. 50, 1036 (1966) [Sov. Phys.-JETP 23, 689 (1966)].
[6] A.S. Bakai, Nuclear Fusion 10, 53 (1970).
[7] L.I. Rudakov and L.V. Korablev, Zh. Eksp. Teor. Fiz. 50, 220 (1966) [Sov. Phys.-JETP 23, 145 (1966)].
[8] G.M. Zaslavskii and S.S. Moiseev, Zh. Tekh. Fiz. 34, 410 (1964) [Sov. Phys. -Tech. Phys. 9, 324 (1964)].
[9] E.A. Kornilov, E.V. Lifshitz, and O.F. Kovpik, Ukr. Fiz. Zh. 13, 573 (1969).

INVESTIGATION OF MASS TRANSPORT OF He^3 IN LIQUID HeI BY THE THERMAL-NEUTRON METHOD

G.M. Drabkin, V.A. Noskin, and A.Z. Yagud
Leningrad Institute of Nuclear Physics, USSR Academy of Sciences
Submitted 13 March 1972
ZhETF Pis. Red. 15, No. 9, 504 - 508 (5 May 1972)

An investigation of transport phenomena in liquid helium near T_λ is of undoubted interest for a wide circle of problems connected with phase-transition physics. However, the available experimental data are insufficient for an unambiguous clarification of the physical picture of the phenomenon [1 - 5]. At the same time, the large cross section for the absorption of thermal neutrons by He^3 nuclei makes it possible to obtain direct data on the mass transport of the isotope in relatively weak solutions (∿1%) [6].

The measurement principle consists of the following: a capillary filled with liquid He^4 is connected at a definite instant of time to a ∿1% solution of an He^3-HeI mixture with a volume 200 - 300 times the volume of the capillary. The entire system is at a specified temperature, and the amount of He^3 passing through the capillary during the mass-transport process is determined from the change of the intensity of the neutron beam penetrating through it:

$$I/I_0 = \exp(-\sigma N), \tag{1}$$

where I_0 and I are the intensities at the initial instant of time (t = 0) and at the instant of time t, respectively, N is the total number of He^3 atoms that have entered the investigated volume by the time t, and σ is the cross section for the thermal-neutron absorption by the He^3 nuclei. High sensitivity of the method is ensured by the very large value of σ, which is directly proportional to the wavelength λ of the neutron radiation and in our concrete case (λ = 4 Å) reaches 1.2×10^4 b. The remaining effects of scattering and absorption in the investigated mixture amounted to ∿5 b.